MONITORING, METACOGNITION, AND EXECUTIVE FUNCTION: ELUCIDATING THE ROLE OF SELF-REFLECTION IN THE DEVELOPMENT OF SELF-REGULATION

Kristen E. Lyons and Philip David Zelazo
INSTITUTE OF CHILD DEVELOPMENT, UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINNESOTA, USA

Abstract

While an abundance of research has investigated the development of the automatic and controlled processes through which individuals control their thoughts, emotions, and actions, less research has emphasized the role of the self in self-regulation. This chapter synthesizes four literatures that have examined the mechanisms through which the individual acts in a managerial role, evaluating the current status of the system and initiating regulatory actions as necessary. Taken together, these literatures

Advances in Child Development and Behavior
Janette B. Benson : Editor

(on executive function, error monitoring, metacognition, and uncertainty monitoring) suggest that self-reflection plays a critical role in self-regulation, and that developmental improvements in self-reflection (via increasing levels of conscious awareness and enhanced calibration of monitoring systems) may serve as driving forces underlying developmental improvement (and temperamental individual differences) in children's ability to control their thoughts and actions.

I. Introduction

The development of self-regulation has long been a focus of developmental research. From early observations by Piaget and Vygotsky through contemporary behavioral and neuroscientific investigations, this line of inquiry provides insight into the genetic, neurophysiological, and behavioral mechanisms underlying the willful control of thought, emotion, and action. Self-regulation frees children from reactive, stimulus-driven patterns of responding, allowing them to plan for their future, maintain optimal levels of emotional reactivity, and act in a manner that is consistent with their higher order goals or standards for behaving. As such, this core capacity has critical implications for emotional well-being, social competence, and academic and professional success (Blair, 2002; Blair & Diamond, 2008; Eisenberg, Valiente, & Eggum, 2010; Moffitt et al., 2011).

Accordingly, an extensive body of research has investigated the myriad of automatic and controlled processes that underlie the development of self-regulation (Kochanska, Coy, & Murray, 2001; Schneider & Lockl, 2008; Zelazo, Carlson, & Kesek, 2008). Overall, this line of research has revealed that self-regulation begins to emerge in the first few months of life, as children develop basic motor skills allowing them to engage in rudimentary forms of self-soothing (e.g., shifting their gaze from aversive stimuli, seeking proximity to their caregivers; Buss & Goldsmith, 1998; Rothbart, Ziaie, & O'Boyle, 1992). Dramatic improvements in self-regulation occur during early childhood as children become increasingly able to control their thoughts (e.g., Paz-Alonso, Ghetti, Matlen, Anderson, & Bunge, 2009), emotions (e.g., Lewis & Stieben, 2004), and actions (e.g., Zelazo, Müller, Frye, & Marcovitch, 2003). However, self-regulation continues to mature until well into adolescence (Best & Miller, 2010; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006; Olson & Luciana, 2008) and probably beyond (e.g., Weintraub et al., 2011). In short, an abundance of research has revealed that clear age-related improvements in the ability to purposefully adjust one's thoughts and behavior are observed in the first two decades of life.

To date, relatively little attention has been directed toward the *self* aspect of self-regulation, including the self-reflective processes that allow children to evaluate their current (internal and contextual) status and initiate corrective adjustments to their ongoing activity. Just as regulatory agencies cannot enforce laws without actually monitoring whether companies are adhering to them, human self-regulatory systems cannot adequately control their behavior without some degree of awareness of the ongoing operations of the system.

How do children develop the ability to monitor and modify their ongoing thoughts, emotions, and actions? The aim of this chapter is to provide an integrative review of four diverse literatures (on executive function (EF), metacognition, uncertainty monitoring, and error monitoring) that are beginning to converge on this question and that collectively provide some promising answers to it.

Before proceeding, we note that self-regulation encompasses a broad range of automatic and controlled processes (Lewis & Todd, 2007). Our primary focus will be the development of the latter. However, age-related changes and individual differences in automatic processes likely interact with more controlled operations to yield self-regulation, as discussed in later sections of this chapter. We also note that the terms self-monitoring and self-regulation are used here as functional constructs. That is to say, these and related terms (see Table I for a list of key constructs) are intended to describe the processes that make it possible for individuals to track and adjust their behavior (e.g., Zelazo et al., 2008), and not as the operations of a homunculus or neural module.

II. Four Literatures Investigating the Development of Self-Regulation

The question of how children acquire the ability to purposefully control their thoughts and actions has received considerable attention in recent years, in part due to the well-documented importance of self-regulation for daily functioning and long-term interpersonal, academic, and professional success (Blair, 2002; Blair & Diamond, 2008; Eisenberg et al., 2010; Manly, Hawkins, Evans, Woldt, & Robertson, 2002; Moffitt et al., 2011). Given that self-regulation involves a highly complex array of processes, different researchers have focused on different aspects of self-regulation and approached the topic in different ways, generating at least four disparate research literatures on EF, error detection, metacognition, and uncertainty monitoring. While each approach offers distinct methodological advantages and unique insight into the development of self-regulation, they

Table I
Key Constructs

Key construct	Definition
Self-regulation	The broad range of automatic and controlled processes through which thoughts, emotions, and actions are adjusted
Self-control	The deliberate adjustment of one's cognitive, emotional, or behavioral responses
Self-reflective awareness	The capacity to evaluate one's ongoing thoughts, emotions, and actions
Executive function	The deliberate adjustment of one's cognitive, emotional, or behavioral responses, often conceptualized as the cognitive processes of flexibility (task switching), inhibitory control, and working memory
Error monitoring	Tracking one's performance on a task and noticing when one has committed an error, often assessed using ERP
Metacognition	Awareness and control of one's cognitive activity
Metacognitive monitoring	Reflecting on one's ongoing cognitive activity
Metacognitive control	Top-down control of cognitive activity based on metacognitive monitoring evaluations
Uncertainty monitoring	Evaluating how certain one feels about the likely accuracy of one's responses
Interoception	Subjective awareness of one's physiological, emotional, and cognitive states
Fringe consciousness	An indirect means of monitoring, such that individuals are implicitly aware of lower-order cognitive operations, which gives rise to subjective feelings of knowing (although they cannot explicitly reflect on the source of the subjective feelings)

have progressed relatively independently of one another. However, even a cursory review of these literatures reveals important ways in which the core processes under investigation may be fundamentally intertwined. In what follows, we survey these literatures and emphasize how developmental changes in each may be critically dependent on age-related increases in self-reflection. Taken together, these literatures provide a more comprehensive characterization of the development of self-reflection and its myriad consequences for behavior.

A. EXECUTIVE FUNCTION

EF entails the conscious control of thoughts and actions (Zelazo et al., 2008) and refers to the more controlled, top-down processes in self-regulation that depend importantly on neural circuits involving prefrontal cortex (PFC). Although it has widespread consequences for daily functioning (e.g., maintaining focus on one's current task, inhibiting oneself from becoming distracted, flexibly shifting one's attention during multitasking), EF is typically assessed using neuropsychological tests of prefrontal cortical function that have been modified for use with children (e.g., go/no-go, backward digit span, flanker; Fernandez-Duque, Baird, & Posner, 2000). Often, these tasks require children to overcome the tendency to respond reflexively, impulsively, or by habit (Davidson, Amso, Anderson, & Diamond, 2006; Shimamura, 2000) and instead purposefully select the appropriate course of action.

EF emerges relatively early, as indicated by infants' passing of the A-not-B task toward the end of the first year of life. In this task, infants are repeatedly shown an object being hidden in a certain location (location A) where they repeatedly retrieve the object. Next, the object is conspicuously hidden in a different location (location B). Whereas 8- to 10-month-old infants typically search for the object in location A, older infants typically search for the object in location B, indicating that they were able to inhibit their habitual, prepotent response to search for the object where it was previously retrieved (Marcovitch & Zelazo, 2009). According to one view, this achievement is critically dependent upon infants' emerging ability to mentally represent elements of the task at hand by reflecting upon the contents of lower levels of processing. This psychological distancing allows infants to decouple themselves from the stimulus–response pattern of searching (in location A), permitting them to selectively direct their searching to location B (Marcovitch & Zelazo, 2009).

EF continues to improve throughout childhood and adolescence as individuals become able to achieve increasingly higher levels of reflections of their ongoing mental activity. Developmental improvements in EF accuracy are particularly dramatic during early childhood, when rapid increases are observed in the highest level of consciousness that children can experience (Zelazo, Gao, & Todd, 2007). During middle childhood, as children gain metacognitive awareness of the effects of response speed on performance accuracy (namely that faster responses are more likely to be incorrect), a trade-off between speed and accuracy begins to emerge (Best, Miller, & Jones, 2009; Davidson et al., 2006) along with overall improvements in reaction times on EF tasks. Performance on many EF tasks does not reach adult levels until well into adolescence, coinciding with the rather protracted structural and functional maturation of PFC, which supports EF (Barnea-Goraly et al., 2005; Blakemore & Choudhury, 2006; Gogtay et al., 2004).

Research with adults indicates that distinct aspects of EF are supported by distinct regions of PFC. Specifically, the capacity to inhibit oneself from responding impulsively and the capacity to adjust one's behavior so that the correct course of action is selected (e.g., on conflict tasks such as the Stroop color–word task or the flanker task; Gerstdat, Hong, & Diamond, 1994; Rueda et al., 2004) have distinct neural substrates (Garavan, Ross, Murphy, Roche, & Stein, 2002). These findings are relevant for the development of self-regulation in two ways. First, given that distinct regions of PFC mature at different rates (e.g., Bunge & Zelazo, 2006; Gogtay et al., 2004), these finding suggest that subdomains of EF may follow distinct developmental trajectories. This notion is well supported by the literature (Best et al., 2009; Huizinga, Dolan, & van der Molen, 2006): Whereas inhibitory control and performance on conflict tasks (requiring flexible shifting of attention to relevant task dimensions) undergo substantial developmental improvement during early childhood (Gerstdat et al., 1994; Jacques & Zelazo, 2001; Rueda et al., 2004), selective attention, working memory, problem solving, and planning ability continue to improve steadily throughout childhood and adolescence (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Best et al., 2009; Huizinga et al., 2006).

Second, these findings underscore two critical roles of the "executive" in executive functioning: first, to evaluate one's ongoing performance in order to reign in responding when contextual cues indicate that it is necessary to do so; and second, to reflectively adjudicate among response alternatives to select the appropriate course of action. Such distinctions are helpful in understanding how different aspects of EF develop (Garavan et al., 2002). While there is some debate concerning the underlying structure of EF (i.e., whether it is best characterized as a unitary or modular function; e.g., Best et al., 2009), it is generally agreed that EF includes at least three core skills: working memory, inhibitory control, and cognitive flexibility (e.g., Hughes, 1998; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

1. Working Memory

Working memory, individuals' capacity to maintain and manipulate information in short-term memory, steadily improves throughout childhood and adolescence (Siegel & Ryan, 1989). With age, the maximum number of items that individuals can retain (i.e., working memory capacity) steadily increases (e.g., Klingberg, Forssberg, & Westenberg, 2002), as does their ability to mentally manipulate information (e.g., Kwon, Reiss, & Menon, 2002). One's ability to maintain and manipulate information likely has critical consequences for self-regulation, as appropriate regulation requires that one reason about two or more potential response alternatives in accordance with the parameters of the current context and knowledge about the capabilities and limits of the system. As such, age-related improvements in the ability to reflect upon and reason about relevant features of task performance likely are an important factor underlying age-related improvements in self-regulation (e.g., Zelazo, 2004).

2. *Inhibitory Control*

Inhibitory control entails the capacity to willfully withhold or suppress a thought or action (Best et al., 2009; Paz-Alonso et al., 2009; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). This capacity is often assessed by examining children's ability to refrain from producing a prepotent response (e.g., on a go/no-go task; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009), although it is sometimes also assessed in more emotional contexts (e.g., by examining children's ability to refrain from peeking at a present or their ability to suppress their disappointment in receiving an undesirable gift; e.g., Carlson & Wang, 2007). In both types of task, successful inhibition requires that children maintain awareness of their ongoing performance and consciously suppress responses that are inappropriate.

Inhibitory control develops throughout childhood and adolescence (Best & Miller, 2010), but improvements in this capacity are particularly dramatic during early childhood (Carlson, 2005; Carlson, Mandell, & Williams, 2004). During this period, children also become increasingly able to delay gratification, electing to forgo smaller immediate rewards in order to receive larger rewards in the future. Whereas elementary school-aged children typically make the advantageous selection, preschoolers are less consistent in their choices, frequently succumbing to their desire for immediate gratification over the long-term benefits of waiting (Mischel, 1974; Thompson, Barresi, & Moore, 1997).

Developmental improvement in the ability to delay gratification appears to be dependent upon children's ability to mentally connect their present and future selves (Lemmon & Moore, 2007). Although children display mirror self-recognition around 2 years of age (as indicated by passing the mirror test; Amsterdam, 1972), and some aspects of self awareness likely emerge gradually before that (Rochat, 2004), it is not until around age 4 that children seem to appreciate that who they are in the present moment is the same individual who experienced past events and who will experience future events (Moore & Lemmon, 2001; Povinelli, Landau, & Perilloux, 1996). Thus, younger children may fail delay of gratification tasks because they simply fail to appreciate that their actions will affect their future (so for them, choosing an immediate reward may represent the logical decision). As children develop the ability to represent their both present and future selves and to reason about the consequences of current actions on the future self, children more consistently make the decision that is more advantageous over the long run.

In addition to dramatic developmental differences in inhibitory control, there are substantial individual differences in inhibitory control that are relatively stable throughout early childhood, as indicated by performance on behavioral measures and by parental reports of aspects of temperament related to self-regulation (e.g., Carlson et al., 2004; Kochanska, Murray, & Harlan, 2000). Moreover, it has long been known that children vary significantly in their performance on delay of gratification tasks (with individual differences at age 4 predicting academic and social success into adolescence; e.g., Shoda, Mischel, & Peake, 1990). The presence of systematic differences in individuals' ability (or propensity) to inhibit inappropriate thoughts or actions raises intriguing questions about whether individuals differ in their ability to *access* the contents of their mental activity and/or whether they differ in the *quality* of the to-be-accessed material (i.e., whether they are actually receiving a stronger "signal" to be read). Of course these alternatives are not exclusive, and the source of differences in inhibitory control may vary.

3. Cognitive Flexibility

Although inhibitory control can be isolated in laboratory tasks, in the real world, inhibitory control demands are often intertwined with demands for shifting one's attention or response set to coincide with an updated context (e.g., Bunge & Zelazo, 2006). Similar to inhibitory control, this capacity undergoes substantial developmental improvement during early childhood. For example, on the dimensional change card sort task, children are presented with cards varying in two dimensions (e.g., color and shape). Children are first asked to sort the cards by one dimension (e.g., color) and then to sort the cards by the other dimension (e.g., shape). While most 4-year-olds typically succeed in sorting by the second dimension, the majority of 3-year-olds usually fail to do so, persisting in sorting by the first dimension (despite being able to articulate the rules of the current task; Zelazo, Frye, & Rapus, 1996). This failure appears to arise from young children's inability to consider the two dimensions in contradistinction (i.e., in the color game, you should sort by color with red here and blue there, BUT in the shape game you should sort by shape, with rabbits here and boats there), arising from limitations in the degree of iterative self-reflection that they can engage in. As children become increasingly capable of integrating mental representations of lower-order cognitive operations, they are increasingly able to willfully and flexibly shift their responses, overcoming their perseverative tendencies (Zelazo et al., 2003).

The preschool years are marked by substantial age-related improvements in cognitive flexibility, as indexed by children's performance on conflict EF tasks (in which children must inhibit a prepotent response and instead engage in a less automatized response; e.g., Carlson & Moses, 2001). For example, performance on Stroop-like tasks (in which the correct response conflicts with one's natural tendency, e.g., to say "day" to a picture of a moon and to say "night" to a picture of a sun) improves significantly between early and middle childhood (Gerstdat et al., 1994), as does performance on Simon Says (Strommen, 1973) and flanker tasks (in which children must indicate which direction a central arrow points, while the surrounding arrows may point in similar or opposite directions; e.g., Rueda et al., 2004). As in the A-not-B task (e.g., Diamond & Doar, 1989; Marcovitch & Zelazo, 1999), flexible responding requires that one *reflectively* choose the appropriate response, rather than *reflexively* responding with the prepotent response.

The results of event-related potential (ERP) studies suggest that successful performance on such tasks involves two phases: conflict detection and conflict resolution (i.e., selecting the appropriate response; e.g., Rueda et al., 2004). Children's ERP responses on both of these phases are slower than adults', suggesting that developmental improvement in flexible responding in the face of conflict may result from improvements in children's ability to detect conflict and their ability to resolve conflict (by selecting the appropriate response; Rueda et al., 2004).

4. Summary

In sum, research on EF indicates that children's ability to control their thoughts and actions improves substantially during early childhood and continues to improve gradually into adolescence. One approach to these improvements suggests that they arise from age-related increases in children's capacity to consciously reflect upon their lower-order mental processes, affording them with the psychological distance to evaluate their ongoing performance, adjudicate among response alternatives, and flexibly adapt their behavior to changing contexts.

B. ERROR MONITORING

Originating from research in cognitive neuroscience, the error monitoring approach to the study of self-regulation focuses on individuals' ability to monitor their performance on a task. Specifically, this approach focuses on whether individuals detect when they have committed an error and whether they adjust their behavior accordingly in order to improve the accuracy of their performance on subsequent trials (e.g., Ridderinkhoff, van den Wildenberg, Segalowitz, & Carter, 2004).

An abundance of research with adults has implicated the medial PFC generally, and the anterior cingulate specifically, as critical areas supporting performance monitoring, response selection, and performance adjustment (e.g., Ridderinkhoff, van den Wildenberg, et al., 2004). The basis of performance monitoring is a topic of debate, with some contending that performance monitoring is achieved via conflict monitoring (i.e., detecting when the appropriate response is not clearly apparent, and thus, one should proceed with caution; e.g., Carter & van Veen, 2007) and others contending that performance monitoring is achieved via outcome monitoring (i.e., evaluating whether outcomes are worse than expected; e.g., if one has made an erroneous response, missed a response deadline, or received negative feedback; Holroyd & Coles, 2002). However, it is generally accepted that the function of performance monitoring operations is to alert the cognitive control system when increased control is required to achieve acceptable performance levels (e.g., McGuire & Botvinick, 2010; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004).

The neural hallmark of the error monitoring system is a frontally generated negative deflection in the ERP waveform, termed the error-related negativity or ERN, that is initiated at the onset of an erroneous response and peaks about 100 ms post-response. This is sometimes followed by a positive deflection (PE) that peaks at about 500 ms post-response. Whereas the ERN appears to be automatically generated and observed for all errors, the amplitude of the PE predicts subsequent response slowing and seems specifically associated with errors that an individual consciously recognizes (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). It has been suggested that the PE may be indicative of individuals' evaluation of the error (as its time course and topography is similar to the P3; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005).

The ERN and PE have been functionally localized to the anterior cingulate cortex (ACC), a region that is ideally positioned to serve as an interface between monitoring and control operations, as its dorsal region has projections to areas involved in response selection and cognitive control, including the dorsolateral PFC and motor regions, and its rostral–ventral region has projections to limbic structures (which may result in negative affective reactions in response to erroneous responses; Wiersema, van der Meere, & Roeyers, 2007, cf. the somatic marker hypothesis; Damasio, 1996). Consistent with such a division, the ERN has been localized to the dorsal region of ACC, while the PE has been localized to the rostral/ventral region (Herrmann, Rommler, Ehlis, Heidrich, & Fallgatter, 2004; Van Boxtel, Van der Molen, & Jennings, 2005; van Veen & Carter, 2002).

Although the ERN was initially noted as occurring just before the commission of an error (e.g., on a go/no-go task), it has since been shown that the ERN also appears following negative feedback and after late responses on tasks with a response deadlines (Holroyd & Coles, 2002). The ERN is also observed on correct responses when trials involve a high degree of conflict (e.g., on incongruent trials on a flanker task). Moreover, the amplitude of the ERN correlates with the magnitude of the error (e.g., if one's response was similar versus very different from the correct response) and error value (e.g., if one will receive a small or large penalty for the mistake; Ridderinkhoff Ullsperger et al., 2004). Thus, this system appears to be quite adept at evaluating the quality of one's performance using a variety of indicators of performance acceptability.

Developmental research indicates that ERN amplitude increases with age from at least around age 8 years through early adulthood, while PE amplitude remains relatively age invariant (e.g., Davies, Segalowitz, & Gavin, 2004; Wiersema et al., 2007). Further, although children's reaction times are generally slower than adults', post-error slowing (i.e., the tendency to respond more slowly following trials on which one has committed an error, as compared to following trials on which one responded correctly) is relatively age invariant between childhood and adulthood (Wiersema et al., 2007; but see also Hogan, Vargha-Khadem, Kirkham, & Baldeweg 2005). Hence, error monitoring (i.e., ERN amplitude) increases with age, but self-correction in the face of erroneous responding remains relatively constant across age.

This curious collection of developmental findings surrounding the ERN has generated speculation concerning error monitoring systems and their neural generators. One account posits that the ERN and PE may arise from parallel error monitoring systems supported by distinct regions (with those generating the PE maturing earlier in development than those generating the ERN; Wiersema et al., 2007). From this perspective, individuals monitor their performance at a relatively implicit level (generating the ERN) as well as at more explicit level (generating the PE). Given the neural connectivity between ACC and PFC (Ridderinkhoff et al., 2004), implicit monitoring operations (of conflict or outcomes) could automatically signal to prefrontal structures that enhanced cognitive control is required. This would result in enhanced performance accuracy on subsequent trials, without the need for explicit reflection. That is, the system may be aware of its performance, without the individual having access to this knowledge about the system. Conscious error monitoring (signified by the PE) may offer an alternative route to self-regulation, with explicit awareness of inadequate performance yielding additional reasoning-based adjustments (e.g., the implementation of strategies for increased performance accuracy).

Alternatively, this collection of findings may be observed because the ERN is generated as a result of neural connectivity between PFC and ACC, rather than being generated simply from the ACC, as is commonly believed (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). Support for this notion comes from the findings that patients with ACC lesions are aware of errors but fail to produce an ERN (Stemmer, Segalowitz, Witzke, & Schönle, 2004) and adolescents with white-matter lesions in PFC exhibit reduced ERN amplitudes (Gehring & Knight, 2000). This theory would also account for the finding that ERN amplitude is associated with post-error slowing in adult populations (Ridderinkhoff et al., 2004). From this perspective, error detection may be decoupled from error correction, especially in young children. With increasing age, however, the two systems may become functionally intertwined, such that in adults, error correction more reliably follows error detection.

In addition to striking developmental differences, marked individual differences in ERN have been noted. Higher degrees of socialization in children (e.g., increased understanding of manners and norms for behavior) are associated with increased ERN amplitude (Santesso, Segalowitz, & Schmidt, 2005). Increased ERN amplitude is also observed in children with anxiety disorders compared to age-matched controls. However, no differences in PE amplitude are observed between these groups (Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006; McDermott et al., 2009). ERN amplitude is also negatively correlated with risk taking and sensation seeking in adolescent males (Santesso & Segalowitz, 2009). Experimentally increasing the stakes for erroneous responses yields increases in ERN amplitude. Individuals high in conscientiousness are not affected by this manipulation, however, presumably because they already exhibit high-amplitude ERNs, even for low-consequence errors (Pailing & Segalowitz, 2004). Thus, while children become generally more capable of monitoring their performance on a task with increasing age, there may also be endophenotypic differences in the degree to which individuals are neurophysiologically sensitive to errors. Similar to inhibitory control, these differences may arise as a result of differences in the strength of the neural signal or in individuals' ability or propensity to reflect upon that signal.

1. Summary

In short, the error monitoring literature offers a neural account for how individuals are able to adaptively control their behavior by monitoring their ongoing performance and adjusting their attentional control and behavioral responses, based on the results of monitoring evaluations. Age-related improvements in self-regulation are generally thought to arise from age differences in children's ability to monitor their performance accuracy, consistent with the emphasis on self-reflection noted in the literature on EF. However, we cannot rule out the possibility that improvements in self-regulation might also result from age-improvements in children's ability to translate the results of their monitoring evaluations into effective self-corrective adjustments.

C. METACOGNITION

A third literature investigating the development of self-regulation is metacognition, or the study of how individuals monitor their ongoing mental activity and use the results of these evaluations to guide their subsequent cognitive or behavioral responses (Flavell, 1979; Lyons & Ghetti, 2010; Nelson & Narens, 1990). The notion that individuals have the capacity to evaluate their ongoing mental activity (i.e., introspection) has a long history in psychology (as noted by James, 1890, a characteristic quality of the mature, adult mind is that it knows what it knows).

Piaget proposed that introspective awareness of one's thoughts is an aspect of cognitive development that appears to emerge around age 7 (Fox & Riconscente, 2008). Notably, this is approximately the same age that Flavell and colleagues established as the age at which children become aware of their thoughts in stream of consciousness (Flavell, Green, & Flavell, 1995, 2000). Similarly, Vygotsky noted that children's awareness of their cognitions, including attention and memory, follow a rather protracted time course (Fox & Riconscente, 2008), consistent with the results of later research investigating children's explicit understanding of aspects of memory functioning. For example, children gradually come to understand that to forget something, one must have already remembered it, and that some types of material (such as lists organized around a theme) are easier to remember than others (such as lists of random items) (Kreutzer, Leonard, & Flavell, 1975).

Contemporary conceptualizations of metacognition typically distinguish between two levels of function. The first is the cognitive level, where basic cognitive functions (e.g., memory, attention, learning) occur. The second is the metacognitive level which monitors the operations occurring at the cognitive level (i.e., metacognitive monitoring) and controls the operations occurring at the cognitive level in a top-down manner (i.e., metacognitive control; Nelson & Narens, 1990; Pasquali, Timmermans, & Cleermans, 2010; Plude, Nelson, & Scholnick, 1998). Research on metacognition thus generally focuses on the extent to which children maintain ongoing explicit awareness of their cognitive activities and the role of explicit awareness of ongoing cognitive activity in guiding behavioral adjustments (in contrast to the more implicit or mixed levels of monitoring that are emphasized in the EF and error monitoring literatures).

1. Metacogntive Monitoring

Typically, metacognitive research involves collecting introspective reports from individuals, for example, asking individuals to report how certain they are about the accuracy of their response on a particular trial or how well they have learned the items on a list of words. Metacognitive insight is assessed by examining the degree to which participants' introspective judgments correspond with their performance on the task (i.e., response accuracy or reaction time).

Metacognitive monitoring may take many forms depending upon the task at hand and the individuals' progress on a task (Lyons & Ghetti, 2010). For example, a student who is studying for an exam might evaluate how well she has mastered different aspects of the test material (i.e., a *judgment of learning*; Metcalfe, 2009; e.g., "How well have I learned this material?") to decide how to allot her remaining study time. Alternatively, a person might experience a tip of the tongue phenomenon when trying to remember the name of a restaurant to recommend to a friend (i.e., a *feeling-of-knowing* that one possesses a given piece of knowledge although it is not immediately recallable; Hart, 1965; e.g., "I know that I know this information, but I cannot bring it to mind."). Or, a witness to a crime might be asked how certain she is that the individual on trial was the perpetrator that she saw commit a robbery (i.e., a *confidence judgment*; Ghetti, Lyons, Lazzarin, & Cornoldi, 2008; e.g., "How sure am I that my memory is correct?").

There is some debate concerning the source of metacognitive judgments, namely whether they are achieved via direct access to the actual contents of mental activity (e.g., whether confidence judgments about learning or response accuracy stem from reflective evaluations of one's knowledge) or whether metacognitive judgments correspond to inferences based on heuristic cues concerning qualities of the cognitive experience (Koriat, 2000; Scott & Dienes, 2010). A growing body of research supports the latter point of view. For example, there is evidence that judgments of learning are based on how fluently one processes the material being learned (Benjamin, Bjork, & Schwartz, 1998; Koriat & Ma'ayan, 2005; Koriat, Ma'ayan, & Nussinson, 2006; Matvey, Dunlosky, & Guttentag, 2001). Indeed, adults' feeling-of-knowing judgments appear to be driven by the familiarity of the question being asked, rather than the amount of information that is actually retrieved (e.g., Schwartz, 2002).

Developmental research indicates that, like adults, children base their metacognitive judgments on heuristic cues (e.g., latency to retrieve a response), although the magnitude of their reliance on such cues may increase with age (Koriat & Ackerman, 2010, see also Lockl & Schneider, 2002). Hence, metacognitive judgments may be characterized as "intuitive feelings" (Price & Norman, 2008) arising from subjective features of the decision-making experience. Following William James, some researchers have speculated that while these fleeting metacognitive experiences are clearly consciously accessible, they represent a fringe consciousness, as the individual is implicitly aware of what they know, which gives rise to the subjective feelings, of which they are aware. However, the individual is not consciously aware of the knowledge that generates these feelings (Norman, Price, & Duf, 2010). From this perspective, metacognitive judgments may actually reflect content knowledge even if the judgments are arrived at indirectly. Consistent with this proposal, experimental studies using implicit learning paradigms suggest that differences in fringe experiences, such as hunches about the correct response, do not simply arise from differences in heuristic cues (e.g., familiarity). Rather, they appear to be influenced by individuals' content knowledge, even though individuals cannot consciously reflect upon this content (e.g., Dienes, Altmann, Kwan, & Goode, 1995). Moreover, experiences that arise in fringe consciousness may lead to efforts by the individual to bring the source of these feelings into full conscious awareness, resulting in a more analytical, rather than intuitive, form of self-reflection (Norman et al., 2010). Thus, while debate concerning the source of metacognitive judgments is typically framed in terms of an either-or question, monitoring of ongoing cognitive performance likely arises from evaluations at multiple levels of conscious access, similar to EF and error monitoring.

Neuroimaging research with adults has begun to investigate the neural substrates of interoception, or individuals' subjective awareness of their physiological, cognitive, or emotional states (e.g., Craig, 2002; Khalsa, Rudrauf, Feinstein, & Tranel, 2009). This work has implicated the insula and ACC as critical structures supporting conscious awareness of these states. Individual differences in the size of the ACC are correlated with introspective accuracy (Fleming, Weil, Nagy, Dolan, & Rees, 2010), and ACC and insula activity are correlated with the strength of feeling-of-knowing judgments (Craig, 2009). Thus, like error monitoring, interoception appears to be supported by structures in medial PFC, including the ACC.

What neural mechanisms might underlie interoception and metacognitive monitoring more generally? Computational modeling suggests that by evaluating the *coherence* of a neural signal in response to a query, such as a question about whether an item on a memory test is old or new, neural systems may be able to "know when they know" (Pasquali et al., 2010). One can easily see how such a mechanism may underlie the findings that fluency and familiarity are associated with high degrees of confidence, feelings-of-knowing, and judgments of learning.

Alternatively, Craig (2002, 2009) has argued that by integrating neural signals from all of the inputs that the body receives at a given moment, including physiological sensations (e.g., hunger, satiation, pain), emotional experiences (e.g., empathic concern), motor and proprioceptive experiences (e.g., body movement), motivational sensations (e.g., reward signals), as well as environmental input (e.g., cues concerning social or physical risk), the insula generates a "meta-representation of the 'global emotional moment'" (Craig, 2009, p. 67), giving rise to a personal sense of agency and subjective sense of knowing oneself.

Developmental research indicates that metacognitive monitoring follows a protracted developmental time course (see Schneider & Lockl, 2002 for a review). The capacity to monitor one's cognitive operations appears to emerge during the preschool years (Lyons & Ghetti, 2010). Between the ages of 3 and 5 years, children begin to be able to provide feeling-of-knowing judgments that predict their subsequent memory performance (Cultice, Somerville, & Wellman, 1983) and to show conscious awareness of comprehension failures (e.g., comprehension monitoring; e.g., Revelle, Wellman, & Karabenick, 1985). During this period, children also begin to be able to provide crude verbal reports of their mental activity. For example, preschoolers as young as 4 years refer to mental imagery when describing how they make their decisions on a mental rotation task (Estes, 1998). However, it is not until the elementary school years that children become adept at describing the contents of their thoughts in stream of consciousness (Flavell et al., 1995, 2000).

Throughout childhood and into early adolescence, the accuracy of metacognitive judgments improves substantially (e.g., Roebers, 2002; Schneider & Lockl, 2008), with children's metacognitive reports becoming increasingly concordant with their actual performance. This developmental improvement likely results from a number of factors, including age-related reductions in the influence of wishful thinking on metacognitive reports (Schneider, 1998) and age-related increases in children's content knowledge that provide a more accurate foundation for assessing the quality of their performance (Kruger & Dunning, 1999). The accuracy of metacognitive judgments also likely improves as a result of age-related improvements in individuals' ability to psychologically distance themselves from their ongoing mental activity, affording them with a broader perspective of their cognitive activity and its likely outcomes (Zelazo, 2004; Zelazo et al., 2007).

2. Metacognitive Control

Of course, metacognitive insight is only useful to the extent that it can be used to inform the control of behavior. Accordingly, much research has investigated the mechanisms through which individuals adjust their responses based on the self-insight gleaned via metacognitive monitoring (Pasquali et al., 2010).

Like monitoring, metacognitive control may take many forms, depending upon the task at hand and the resources available to the individual. Even very young children engage in rudimentary forms of metacognitive control, for example, by seeking information from knowledgeable adults (e.g., Chouinard, 2007; Koenig & Harris, 2005) or by spending additional time playing with toys when one cannot quickly identify their causal properties (e.g., Schulz & Bonawitz, 2007). With age, children become increasingly able to engage in more advanced forms of metacognitive control, such as slowing down their response times to avoid committing errors (Davidson et al., 2006), refraining from answering questions that they are likely to answer incorrectly (e.g., Koriat, Goldsmith, Schneider, & Nakash-Dura, 2001), or providing more general rather than more specific answers to questions, increasing the likelihood of providing the correct answer (Goldsmith, Koriat, & Weinberg-Eliezer, 2002). Older children and adults may also selectively allocate more attention to more difficult or relevant tasks (e.g., Miller, 1990) or strategically allot their remaining study time to maximize learning (e.g., Metcalfe, 2009).

While these behaviors differ significantly superficially, at their core, they represent means by which individuals may strategically adjust their behavior in order to achieve higher levels of performance accuracy. Models of metacognition posit that when monitoring operations indicate that individuals' current cognitive or behavioral activity is insufficient for achieving one's aims, control operations are engaged to ensure that goals are achieved more effectively or efficiently (e.g., Nelson & Narens, 1990). For example, research with adults indicates that judgments of learning guide the allocation of study time, with individuals discontinuing the study of already mastered material and focusing their attention on the material that is most likely to be learned in the remaining time period, such as the material that is the most well learned but not yet mastered (Metcalfe, 2009).

However, it has been noted that under some conditions, control can occur in the absence of conscious monitoring (Moulin, Perfect, & Fitch, 2002). Indeed, in daily life, it is often the case that individuals seem to automatically regulate their actions with little conscious deliberation. Recall, however, that fringe consciousness affords individuals with implicit awareness of their cognition, and hence the ability to selectively respond in a manner consistent with their intuitive assessment of their ongoing cognitive operations (Norman et al., 2010). In this manner, as in error correction, metacognitive monitoring operations might guide metacognitive control at a relatively implicit level.

Metacognitive control develops gradually over the course of childhood. During the preschool years, children begin to evince rudimentary control strategies (e.g., beginning to selectively seek information from reliable sources (Koenig & Harris, 2005) and withholding incorrect responses on memory tests (Balcomb & Gerken, 2008)). With increasing age, children become more adept at selectively directing their attention and study time to the more advantageous to-be-studied materials (Metcalfe, 2009; Miller, 1990), as well as becoming increasingly well calibrated in their ability selectively to withhold responses that are unlikely to be correct (Balcomb & Gerken, 2008; Koriat et al., 2001).

Although little research has directly investigated the relation between monitoring and control operations in children, it has been hypothesized that one reason children may evince poor metacognitive control skills is that they are challenged in translating their monitoring evaluations into appropriate adjustments in behavior (Metcalfe, 2009; Schneider & Lockl, 2002). In addition, age-related improvements in metacognitive control likely arise as a function of age-related increases in metacognitive insight as children become increasingly equipped with the necessary self-insight to facilitate accurate and appropriate adjustments in behavior.

3. Summary

The metacognitive approach to the study of self-control emphasizes the role of self-reflection on one's current mental activity as a motivator for the initiation of appropriate performance adjustments. From this perspective, age-related improvements in individuals' ability accurately assess their current cognitive performance and, to adaptively alter their subsequent cognitive or behavioral responses in accordance with these evaluations, play a critical role in the development of self-regulation.

D. UNCERTAINTY MONITORING

A spin-off from the metacognitive literature with connections to research on risk-taking and the development of reasoning, research on uncertainty monitoring concerns individuals' capacity to evaluate their subjective sense of certainty about the likely accuracy of a response or decision (Lyons & Ghetti, in press; Roebers, 2002). Uncertainty monitoring is a core aspect of metacognition (Ghetti, Qin, & Goodman, 2002; Howie & Roebers, 2007), but given that uncertainty is such a pervasive feature of human existence, and because the topic has generated such a large literature with its own paradigms and theoretical frameworks (e.g., Berenbaum, Bredemeier, & Thompson, 2008; Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Osman, 2010), we consider this topic separately.

Uncertainty monitoring has been investigated under a number of rubrics, including research on infants' developing ability to detect differences in the statistical regularity of events in the environment (e.g., Xu & Garcia, 2008) and children's developing ability to evaluate the conditions under which various degrees of certainty may reasonably be inferred (e.g., Deak & Narasimham, 2003; Fay & Klahr, 1996; Pillow & Anderson, 2006). Here, we focus on research about the development of *subjective* uncertainty monitoring from a perspective that emphasizes self-reflection (e.g., Fleming et al., 2010). Stemming from the eyewitness memory literature, the main approach used in this line of research is to examine whether individuals' confidence judgments differ systematically as a function of the accuracy of their responses (e.g., Bornstein & Zickafoose, 1999). Although research on eyewitness memory tends to underscore dissociations between confidence and accuracy, mainstream cognitive research with adults consistently finds that the two indices are correlated with one another, with individuals reporting higher confidence in their accurate responses than their inaccurate responses (e.g., Robinson, Johnson, & Herndon, 1997). Thus, like judgments of learning or feelings of knowing, confidence judgments appear to provide a reasonably accurate representation of the individuals' knowledge, although these judgments may be arrived at indirectly via monitoring of fluency or familiarity (Robinson & Johnson, 1996).

Developmental research indicates that uncertainty monitoring begins to emerge during the preschool years with children as young as 3 years reporting higher confidence in accurate versus inaccurate responses on perceptual identification tasks (Lyons & Ghetti, in press; see also Ruffman, Garnham, Import, & Connolly, 2001). By age 5 years, children report higher confidence in their responses on memory tests for words studied with a picture (which ought to result in stronger memories) than for words studied without a picture (Ghetti et al., 2002). By age 5, children also report higher confidence in responses on memory tests for repeatedly experienced versus singularly experienced events (Roberts & Powell, 2005). Throughout middle childhood, children become increasingly able to provide confidence judgments that differentiate fine-grained distinctions in the strength of their memory representations (e.g., for events imagined once vs. twice; Ghetti et al., 2008) and they become increasingly able accurately to monitor their certainty under more challenging conditions, such as when they are asked misleading questions (e.g., Howie & Roebers, 2007; Roebers, 2002).

Recent findings suggest that developmental changes in the ability to monitor uncertainty may stem from age-related differences in the availability of reliable heuristic cues. For example, Koriat and colleagues (Koriat & Ackerman, 2010) documented age-related increases between second and fifth grade in children's reliance on response latency as a heuristic for confidence judgments. Response latency became an increasingly reliable predictor of the actual accuracy of responses with increasing age, consistent with the trend that the speed-accuracy trade-off becomes more pronounced with age. Thus, with increasing age, children may receive increasingly reliable signals, via fringe consciousness, as to the likely accuracy of their responses, perhaps as a result of age-related increases in children's ability iteratively to reprocess information (Zelazo, 2004; Zelazo et al., 2007).

Developmental improvement in uncertainty monitoring may also arise as a function of differences in the way children of different ages respond to and reason about the experience of subjective uncertainty. For example, when children initially begin to experience subjective feelings of uncertainty, they may not interpret them as such (Flavell, 2003), and thus may not appreciate that when they feel this way, they are more likely to provide an incorrect response. However, as children come to associate their subjective feelings of uncertainty with higher levels of risk for the production of incorrect responses (perhaps via the maturation of the insula and/or age-related increases in children's ability to concurrently represent and reason about both subjective experiences and outcomes), they may come to identify their feelings as indicating uncertainty, and adjust their actions accordingly (in order to alleviate their uncertainty), contributing to age-related improvements in self-regulation.

Awareness of subjective uncertainty (the sensation that one cannot quickly and easily decide how to proceed) may be a highly effective self-regulation tool. As the counterpart to fluency, which is inherently pleasing (Reber, Schwartz, & Winkielman, 2004), uncertainty is arguably an affectively negative experience. As such, subjective uncertainty may serve as a fundamental inhibitory control mechanism, preventing individuals from engaging in behaviors that are likely to result in negative outcomes.

Moreover, the experience associated with resolving uncertainty (e.g., suddenly gaining insight about the answer to a crossword clue or reading the final chapters of a mystery novel as the criminals are exposed) involves a rush of clarity and fluency, resulting in highly positive sensations (Topolinski & Reber, 2010). Thus, subjective awareness of uncertainty may not simply motivate response inhibition but may also motivate the flexible shifting of one's thoughts or actions to clarify the uncertainty, resulting in enhanced performance accuracy (e.g., Platt & Huettel, 2008).

1. Summary

Research on uncertainty monitoring suggests that age-related improvements in children's subjective awareness of their own feelings of uncertainty have a profound impact on the development of self-regulation, helping children to detect instances when they should proceed with caution and providing them with the motivation to adjust their actions as necessary to ensure adequate performance in changing contexts.

III. Integrating Disparate Literatures

Although these four lines of research have progressed relatively independently of one another, research on EF, error monitoring, metacognition, and uncertainty monitoring (summarized in Table I) shares several common grounds. The processes of interest appear to be supported by overlapping neural substrates in medial PFC, including ACC and insula (Fernandez-Duque et al., 2000; Holroyd & Coles, 2002; Lahat, Todd, Mahy, & Zelazo, 2010; Lamm, Zelazo, & Lewis, 2006; Shimamura, 2000). Investigations rely on overlapping methodological techniques. For example, error monitoring studies often entail recording ERPs while participants complete flanker or go/no-go (i.e., EF) tasks, and uncertainty monitoring, error monitoring, and metacognitive investigations often collect self-monitoring reports from participants. Generally, similar patterns of development are observed across the four literatures, with substantial developmental improvement being observed in early childhood (in EF, metacognition, and uncertainty monitoring) and more gradual development continuing well into adolescence (in all four arenas).

Most critically, however, all four lines of research suggest that age-related improvements in self-regulation are critically dependent upon age-related increase in self-reflection. In the EF literature, it has been suggested that improved self-control results from age- and experience-related increases in children's ability to iteratively reprocess information at lower levels of consciousness, with increased psychological distance affording children with the ability to select their responses flexibly, rather than being limited to stimulus–response patterns of responding. In the error-monitoring literature, age-increases in self-control are attributed to the maturation of neural monitoring systems that evaluate response accuracy and age-related increases in connectivity between regions supporting error detection and PFC regions supporting response selection. In the metacognitive literature, there is evidence that self-regulation improves as children become increasingly aware of their ongoing cognitive activity, and increasingly able to control their thoughts and actions, based on the results of metacognitive monitoring assessments. Finally, research on uncertainty monitoring suggests that with age, children become increasingly able to evaluate the likely outcomes of their responses, via increased awareness of their subjective feelings of certainty, with corresponding changes in behavior aimed at alleviating uncertainty (via inhibitory control or adjustments in responding).

IV. The Role of Self-Reflection in the Development of Self-Regulation

Taken together, these literatures suggest that developmental improvement in self-regulation arises from two sources: (a) age-related improvements in self-reflective awareness, and (b) age-related improvements in the ability to translate information gleaned from self-reflection into appropriate behavioral adjustments. Both of these are likely multifaceted processes occurring at various levels of conscious awareness.

A. SOURCES OF AGE-RELATED IMPROVEMENTS IN SELF-REFLECTIVE AWARENESS

There is some evidence to suggest that, like regulation, monitoring may shift from being externally guided (e.g., performance monitoring based on feedback), to internally guided (e.g., based on endemic signals) (Pasquali et al., 2010). For example, children's learning of response contingencies is much more disrupted by intermittently incorrect feedback than is adults'

(Eppinger, Mock, & Kray, 2009). This finding suggests that with age, children's neural monitoring systems may become better calibrated, perhaps as a result of improvements in connectivity among brain regions feeding into monitoring evaluations.

Developmental research stemming from the somatic marker hypothesis (Damasio, 1996) is consistent with this notion. This hypothesis posits that ventromedial PFC associates facts (i.e., environmental cues, previous responses in a given context) with corresponding internal physiological and emotional sensations. When the same cues are encountered at a different time point, the internal emotional and physiological sensations are automatically reactivated, supporting learning about which behaviors are advantageous and which behaviors are disadvantageous in a given context. Research indicates that between middle childhood and adolescence, skin conductance responses preceding previously punished choices increase significantly (as does the ability to learn about which response options are advantageous vs. disadvantageous; Crone & Van Der Molen, 2007). Hence, with age, children may receive increasingly reliable and potent somatic signals concerning their performance accuracy.

Such improvements in signal quality are likely also accompanied by age-related improvements in children's ability or propensity to "read" these signals. Conceptualizations of EF in terms of increasing levels of consciousness and iterative reprocessing (Zelazo, 2004; Zelazo & Cunningham, 2007) as well as metacognition (Dienes & Perner, 2002) posit that with age, children become increasingly able to take as the contents of their mental activity the contents of lower levels of mental activity. Hence, with increasing age, children may gain better access to information concerning their own performance.

B. SOURCES OF AGE-RELATED IMPROVEMENTS IN IMPLEMENTING REFLECTION-BASED REGULATION

Of course, increased awareness may not directly translate into improved regulation as children's ability to use their subjective knowledge to guide their responding also likely improves with age. In part, this may stem from age differences in children's understanding of the meaning of their subjective feelings. For example, as children come to appreciate the relations between subjective feelings of uncertainty and the likelihood of committing an error, they may be more likely to adjust their behavior in the face of uncertainty, resulting in improvements in self-regulation. From this perspective, age-related improvements in self-regulation may arise from improvements in children's ability to reason about the appropriate way to respond, given their current status.

Relatedly, age-related improvements in self-regulation may arise from increases in the motivational power of self-monitoring evaluations. That is to say, as monitoring signals become increasingly reliable, they may also become increasingly salient, persistent forces influencing children's behavior, directing children to adjust their behavior in order to reduce the negative affective experience associated with erroneous responses.

Finally, as children practice using self-reflection to adjust their behavior to achieve more optimal outcomes, connectivity between regions supporting monitoring and control operations is likely to strengthen and become more efficient, leading to an increased automatization of appropriate control adjustments in response to different monitoring signals.

1. Summary

Developmental differences in self-regulation likely arise as a consequence of age-related changes in children's self-reflective awareness of their ongoing task performance, and their ability to use self-insight to implement appropriate behavioral or cognitive adjustments. This appears to be a multifaceted process, with changes in both automatic and controlled functions contributing to improvements in children's ability to strategically regulate their own behavior.

V. Dynamic Interactions Between Automatic and Controlled Processes in Self-Regulation

In addition to striking developmental differences in self-regulation, longitudinal research suggests that individual differences in EF and aspects of temperament related to self-regulation are relatively stable over childhood (e.g., Carlson et al., 2004, Kochanska et al., 2000), raising the intriguing question of why some individuals are better at controlling themselves than are others. In part, this may arise from relatively stable differences in children's environments. For example, recent findings suggest that parents who are generally more sensitive to their children's needs, providing scaffolding, appropriate pacing, and helpful feedback that helps children to succeed on tasks, tend to have children who exhibit better EF (Bernier, Carlson, & Whipple, 2010). From this perspective, individuals may differ in their self-regulation ability as a result of differences in the quality of training that self-regulatory systems receive.

Alternatively, differences in self-regulation may arise from relatively endemic differences in the extent to which individuals are (neurophysiologically and behaviorally) sensitive to errors (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Research from the social psychological literature indicates that tolerance of uncertainty varies significantly between individuals (e.g., Weary & Jacobson, 1997), and error-monitoring research indicates that individual differences in ERN amplitude are associated with personality in children and adolescents, with a reduced ERN being observed in children who are poorly socialized and adolescents who are high in risk-taking (Santesso et al., 2005). On the opposite end of the anxiety spectrum, individuals with obsessive–compulsive disorder and anxiety disorder, who are highly concerned about negative outcomes, show higher ERN amplitudes than control participants (Santesso, Segalowitz, & Schmidt, 2006). Thus, it seems reasonable to speculate that differences in self-regulation may stem (at least in part) from individual differences in the degree to which low-level monitoring operations signal to the individual the need for caution. That is to say, some individuals may simply care less about making mistakes, acting rather impulsively without much concern for the potentially negative outcomes that may result from their behavior because their neural responses to risk and ambiguity may be generally dampened.

An informative new direction for future research would thus be to collect an independent measure of concern for accurate performance as well as estimates of monitoring and control ability. Results could provide insight into the factors contributing to individual differences in self-regulation, as well as how the relative contribution of these factors to self-regulation changes over the course of development. For example, the emergence of the speed-accuracy trade-off during childhood may be attributable to age-related increases in children's concern about committing errors.

There is a growing recognition that self-regulation always results from dynamic interactions between top-down influences (e.g., EF) and bottom-up influences (e.g., physiological arousal, stress, anxiety, motivation) (Blair & Dennis, 2010; Zelazo & Cunningham, 2007). However, the influence of automatic processes on children's self-regulation remains poorly understood. Future research elucidating the nature of this interaction and how it changes over the course of development will provide invaluable new insight into the development of self-regulation.

Finally, future research is necessary to elucidate the complex interactions between automaticity and conscious self-monitoring. While increases in task automaticity ought to free up resources that could be dedicated to self-monitoring (and thus, increases in automaticity may generally be correlated with increased self-monitoring), if automaticity surpasses a certain threshold, individuals may become less able or prone to monitor themselves on the task. Thus, automaticity and monitoring may interact in a nonlinear manner, and this relation may change with age.

VI. Conclusions

Over the course of childhood and adolescence, individuals become increasingly responsible for, and increasingly capable of, regulating their own thoughts, emotions, and actions. Converging evidence from diverse literatures on monitoring, EF, and metacognition suggest that age-related improvements in children's ability to willfully alter their patterns of thought and action may be critically dependent upon age-related improvements in self-reflective awareness and the corresponding deliberate adjustment of behavior. We believe that only by integrating these approaches, theoretically and experimentally, will a comprehensive understanding of the development of self-regulation be achieved.

REFERENCES

Amsterdam, B. (1972). Mirror self-image reactions before age two. *Developmental Biology*, *5*, 297–305.

Anderson, V. A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of executive functions through late childhood and adolescence in an Australian sample. *Developmental Neuropsychology*, *20*, 385–406.

Balcomb, F., & Gerken, L. (2008). Three-year-old children can access their own memory to guide responses on a visual matching task. *Developmental Science*, *11*, 750–760.

Barnea-Goraly, N., Menon, V., Eckert, M., Tamm, L., Bammer, R., Karchemskiy, A., et al. (2005). White matter development during childhood and adolescence: A cross-sectional diffusion tensor imaging study. *Cerebral Cortex*, *15*, 1848–1854.

Benjamin, A. S., Bjork, R. A., & Schwartz, B. L. (1998). The mismeasure of memory: When retrieval fluency is misleading as a metamnemonic index. *Journal of Experimental Psychology. General*, *127*, 55–68.

Berenbaum, H., Bredemeier, K., & Thompson, R. J. (2008). Intolerance of uncertainty: Exploring its dimensionality and associations with need for cognitive closure, psychopathology, and personality. *Journal of Anxiety Disorders*, *22*, 117–125.

Bernier, A., Carlson, S. M., & Whipple, N. (2010). From external regulation to self-regulation: Early parenting precursors of young children's executive functioning. *Child Development*, *81*, 326–339.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*, 1641–1660.

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review*, *29*, 180–200.

Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *The American Psychologist*, *57*, 111–127.

Blair, C., & Dennis, T. (2010). An optimal balance: The integration of emotion and cognition in context. In S. D. Calkins & M. A. Bell (Eds.), *Child development at the intersection of emotion and cognition* (pp. 17–35). Washington, DC: American Psychological Association.

Blair, C., & Diamond, A. (2008). Biological processes in prevention and intervention: The promotion of self-regulation as a means of preventing school failure. *Development and Psychopathology. Special Issue: Integrating Biological Measures into the Design and Evaluation of Preventive Interventions*, *20*, 899–911.

Blakemore, S., & Choudhury, S. (2006). Development of the adolescent brain: Implications for executive function and social cognition. *Journal of Child Psychology and Psychiatry*, *47*, 296–312.

Bornstein, B. H., & Zickafoose, D. J. (1999). I know I know it, I know I saw it: The stability of overconfidence across domains. *Journal of Experimental Psychology. Applied*, *5*, 1–13.

Bunge, S. A., & Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science*, *15*, 118–121.

Buss, K. A., & Goldsmith, H. H. (1998). Fear and anger regulation in infancy: Effects on the temporal dynamics of affective expression. *Child Development*, *69*(2), 359–374.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*, 595–616.

Carlson, S. M., Mandell, D. J., & Williams, L. (2004). Executive function and theory of mind: Stability and prediction from ages 2 to 3. *Developmental Psychology*, *40*, 1105–1122.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*, 1032–1053.

Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development*, *22*, 489–510.

Carter, C. S., & van Veen, V. (2007). Anterior cingulate cortex and conflict detection: An update of the theory and data. *Cognitive, Affective & Behavioral Neuroscience*, *7*, 367–379.

Chouinard, M. M. (2007). Children's questions: A mechanism for cognitive development. *Monographs of the Society for Research in Child Development*, *72*, 1–129.

Craig, A. D. (2002). How do you feel? Interoception: The sense of the physiological condition of the body. *Nature Reviews. Neuroscience*, *3*, 655–666.

Craig, A. D. (2009). How do you feel—Now? The anterior insula and human awareness. *Nature Reviews. Neuroscience*, *10*, 59–70.

Crone, E. A., & Van Der Molen, M. W. (2007). Development of decision making in school-aged children and adolescents: Evidence from heart rate and skin conductance analysis. *Child Development*, *78*, 1288–1301.

Cultice, J. C., Somerville, S. C., & Wellman, H. M. (1983). Preschoolers' memory monitoring: Feeling-of-knowing judgments. *Child Development*, *54*, 1480–1486.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *351*, 1413–1420.

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia. Special issue: Advances in Developmental Cognitive Neuroscience*, *44*, 2037–2078.

Davies, P. L., Segalowitz, S. J., & Gavin, W. J. (2004). Development of error monitoring ERPs in adolescents. *Annals of the New York Academy of Sciences*, *1021*, 324–328.

Deak, G. O., & Narasimham, G. (2003). Is perseveration caused by inhibition failure? Evidence from preschool children's inferences about word meanings. *Journal of Experimental Child Psychology*, *86*, 194–222.

Diamond, A., & Doar, B. (1989). The performance of human infants on a measure of frontal cortex function, the delayed response task. *Developmental Psychobiology*, *22*, 271–294.

Dienes, Z., Altmann, G., Kwan, L., & Goode, A. (1995). Unconscious knowledge of artificial grammars is applied strategically. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *21*, 1322–1338.

Dienes, Z., & Perner, J. (2002). What sort of representation is conscious? *The Behavioral and Brain Sciences*, *25*, 336–337.

Eisenberg, N., Valiente, C., & Eggum, N. D. (2010). Self-regulation and school readiness. *Early Education and Development*, *21*, 681–698.

Eppinger, B., Mock, B., & Kray, J. (2009). Developmental differences in learning and error processing: Evidence from ERPs. *Psychophysiology*, *46*, 1043–1053.

Estes, D. (1998). Young children's awareness of their mental activity: The case of mental rotation. *Child Development*, *69*, 1345–1360.

Fay, A. L., & Klahr, D. (1996). Knowing about guessing and guessing about knowing: Preschoolers' understanding of indeterminacy. *Child Development*, *67*, 689–716.

Fernandez-Duque, D., Baird, J. A., & Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition*, *9*, 288–307.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *The American Psychologist*, *34*, 906–911.

Flavell, J. H. (2003). Varieties of uncertainty monitoring. *Brain and Behavioral Sciences*, *26*, 344.

Flavell, J. H., Green, F. L., & Flavell, E. R. (1995). Young children's knowledge about thinking. *Monographs of the Society for Research in Child Development*, *60*, 1–96.

Flavell, J. H., Green, F. L., & Flavell, E. R. (2000). Development of children's awareness of their own thoughts. *Journal of Cognition and Development*, *1*, 97–112.

Fleming, S. M., Weil, R. S., Nagy, Z., Dolan, R. J., & Rees, G. (2010). Relating introspective accuracy to individual differences in brain structure. *Science*, *329*, 1541–1543.

Fox, E., & Riconscente, M. (2008). Metacognition and self-regulation in James, Piaget, and Vygotsky. *Educational Psychology Review*, *20*, 373–389.

Garavan, H., Ross, T. J., Murphy, K., Roche, R. A. P., & Stein, E. A. (2002). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *Neuroimage*, *17*, 1820–1829.

Gehring, W. J., & Knight, R. T. (2000). Prefrontal—Cingulate interactions in action monitoring. *Nature Neuroscience*, *3*, 516–520.

Gerstdat, C. L., Hong, J. Y., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3 ½ to 7 years old on a Stroop-like day/night task. *Cognition*, *53*, 129–153.

Ghetti, S., Lyons, K. E., Lazzarin, F., & Cornoldi, C. (2008). The development of metamemory monitoring during retrieval: The case of memory strength and memory absence. *Journal of Experimental Child Psychology*, *99*, 157–181.

Ghetti, S., Qin, J., & Goodman, G. S. (2002). False memories in children and adults: Age, distinctiveness, and subjective experience. *Developmental Psychology*, *38*, 705–718.

Gogtay, N., Geidd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., et al. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *101*, 8174–8179.

Goldsmith, M., Koriat, A., & Weinberg-Eliezer, A. (2002). Strategic regulation of grain size in memory reporting. *Journal of Experimental Psychology. General*, *131*, 73–95.

Hart, J. T. (1965). Memory and the feeling-of-knowing experience. *Journal of Educational Psychology*, *56*, 208–216.

Herrmann, M. J., Rommler, J., Ehlis, A. C., Heidrich, A., & Fallgatter, A. J. (2004). Source localization (LORETA) of the error-related negativity (ERN/Ne) and positivity (Pe). *Cognitive Brain Research*, *20*, 294–299.

Hogan, A. M., Vargha-Khadem, F., Kirkham, F. J., & Baldeweg, T. (2005). Maturation of action monitoring from adolescence to adulthood: An ERP study. *Developmental Science*, *8*, 525–534.

Holroyd, C. B., & Coles, M. G. H. (2002). The basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*, 679–709.

Howie, P., & Roebers, C. (2007). Developmental progression in the confidence-accuracy relationship in event recall: New insights provided by a calibration perspective. *Applied Cognitive Psychology*, *21*, 871–893.

Hsu, M., Bhatt, M., Adolphs, R., Tranel, D., & Camerer, C. F. (2005). Neural systems responding to degrees of uncertainty in human decision-making. *Science*, *310*, 1680–1683.

Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *British Journal of Developmental Psychology*, *16*, 233–253.

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia. Special issue: Advances in Developmental Cognitive Neuroscience*, *44*, 2017–2036.

Jacques, S., & Zelazo, P. D. (2001). The flexible item selection task (FIST): A measure of executive function in preschoolers. *Developmental Neuropsychology*, *20*, 573–591.

James, W. (1890). *The principles of psychology.* New York: Holt.

Khalsa, S. S., Rudrauf, D., Feinstein, J. S., & Tranel, D. (2009). The pathways of interoceptive awareness. *Nature Neuroscience*, *12*, 1494–1496.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology*, *24*, 781–791.

Kochanska, G., Coy, K. C., & Murray, K. T. (2001). The development of self-regulation in the first four years of life. *Child Development*, *72*, 1091–1111.

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology*, *36*, 220–232.

Koenig, M. A., & Harris, P. L. (2005). Preschoolers mistrust ignorant and inaccurate speakers. *Child Development*, *76*, 1261–1277.

Koriat, A. (2000). The feeling of knowing: Some metatheoretical implications for consciousness and control. *Consciousness and Cognition*, *9*, 149–171.

Koriat, A., & Ackerman, R. (2010). Choice latency as a cue for children's subjective confidence in the correctness of their answers. *Developmental Science*, *13*, 441–453.

Koriat, A., Goldsmith, M., Schneider, W., & Nakash-Dura, M. (2001). The credibility of children's testimony: Can children control the accuracy of their memory reports? *Journal of Experimental Child Psychology*, *79*, 405–437.

Koriat, A., & Ma'ayan, H. (2005). The effects of encoding fluency and retrieval fluency on judgments of learning. *Journal of Memory and Language*, *52*, 478–492.

Koriat, A., Ma'ayan, H., & Nussinson, R. (2006). The intricate relationships between monitoring and control in metacognition: Lessons for the cause-and-effect relation between subjective experience and behavior. *Journal of Experimental Psychology. General*, *135*, 36–69.

Kreutzer, M. A., Leonard, C., & Flavell, J. H. (1975). An interview study of children's knowledge about memory. *Monographs of the Society for Research in Child Development*, *40*, 1–58.

Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology*, *77*, 1121–1134.

Kwon, H., Reiss, A. L., & Menon, V. (2002). Neural basis of protracted developmental changes in visuo-spatial working memory. *Proceedings of the National Academy of Sciences of the United States of America*, *99*, 13336–13341.

Ladouceur, C. D., Dahl, R. E., Birmaher, B., Axelson, D. A., & Ryan, N. D. (2006). Increased error-related negativity (ERN) in childhood anxiety disorders: ERP and source localization. *Journal of Child Psychology and Psychiatry*, *47*, 1073–1082.

Lahat, A., Todd, R. M., Mahy, C. E. V., & Zelazo, P. D. (2010). Neurophysiological correlates of executive function: a comparison of European-Canadian and Chinese-Canadian 5-year-old children. *Frontiers in Human Neuroscience*, *72*, 1–10.

Lamm, C., Zelazo, P. D., & Lewis, M. D. (2006). Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. *Neuropsychologia*, *44*, 2139–2148.

Lemmon, K., & Moore, C. (2007). The development of prudence in the face of varying future rewards. *Developmental Science*, *10*, 502–511.

Lewis, M. D., Lamm, C., Segalowitz, S. J., Stieben, J., & Zelazo, P. D. (2006). Neurophysiological correlates of emotion regulation in children and adolescents. *Journal of Cognitive Neuroscience*, *18*, 430–443.

Lewis, M. D., & Stieben, J. (2004). Emotion regulation in the brain: Conceptual issues and directions for developmental research. *Child Development*, *75*, 371–376.

Lewis, M. D., & Todd, R. M. (2007). The self-regulating brain: Cortical-subcortical feedback and the development of intelligent action. *Cognitive Development*, *22*, 406–430.

Lockl, K., & Schneider, W. (2002). Developmental trends in children's feeling-of-knowing judgments. *International Journal of Behavioral Development*, *26*, 327–333.

Luu, P., Tucker, D. M., Derryberry, D., Reed, M., & Poulsen, C. (2003). Activity in human medial frontal cortex in emotional evaluation and error monitoring. *Psychological Science*, *14*, 47–53.

Lyons, K. E., & Ghetti, S. (2010). Metacognitive development in early childhood: New questions about old assumptions. In A. Efklides & P. Misailidi (Eds.), *Trends and prospects in metacognition research* (pp. 259–278). New York: Springer.

Lyons, K. E., & Ghetti, S. (in press). The development of uncertainty monitoring in early childhood. *Child Development.*.

Manly, T., Hawkins, K., Evans, J., Woldt, K., & Robertson, I. H. (2002). Rehabilitation of executive function: Facilitation of effective goal management on complex tasks using periodic auditory alerts. *Neuropsychologia*, *40*, 271–281.

Marcovitch, S., & Zelazo, P. D. (1999). The A-not-B error: Results from a logistic meta-analysis. *Child Development*, *70*, 1297–1313.

Marcovitch, S., & Zelazo, P. D. (2009). A hierarchical competing systems model of the emergence and early development of executive function. *Developmental Science*, *12*, 1–18.

Matvey, G., Dunlosky, J., & Guttentag, R. (2001). Fluency of retrieval at study affects judgments of learning (JOLs): An analytic or nonanalytic basis for JOLs? *Memory & Cognition*, *29*, 222–233.

McDermott, J. M., Pérez-Edgar, K., Henderson, H. A., Chronis-Tuscano, A., Pine, D. S., & Fox, N. A. (2009). A history of childhood behavioral inhibition and enhanced response monitoring in adolescence are linked to clinical anxiety. *Biological Psychiatry*, *65*, 445–448.

McGuire, J. T., & Botvinick, M. M. (2010). Prefrontal cortex, cognitive control, and the registration of decision costs. *Proceedings of the National Academy of Sciences of the United States of America*, *107*, 7922–7926.

Metcalfe, J. (2009). Metacognitive judgments and control of study. *Current Directions in Psychological Science*, *18*, 159–163.

Miller, P. H. (1990). The development of strategies of selective attention. In D. F. Bjorklund (Ed.), *Children's strategies: Contemporary views of cognitive development* (pp. 157–184). Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc..

Mischel, W. (1974). Processes in delay of gratification. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (pp. 249–292). San Diego, CA: Academic Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., et al. (in press). *Proceedings of the National Academy of Sciences of the United States of America*.

Moore, C., & Lemmon, K. (2001). *The self in time: Developmental perspectives.* Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Moulin, C. J. A., Perfect, T. J., & Fitch, F. (2002). Metacognitive processes at encoding. In P. Chambers, M. Izaute & P. Marescaux (Eds.), *Metacognition: Process, function, and use* (pp. 35–48). Dordrecht, Netherlands: Kluwer Academic Publishers.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. *The Psychology of Learning and Motivation*, *26*, 125–173.

Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P. H., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology*, *38*, 752–760.

Norman, E., Price, M. C., & Duf, S. C. (2010). Fringe consciousness: A useful framework for clarifying the nature of experience-based metacognitive feelings. In A. Efklides & P. Misailidi (Eds.), *Trends and prospects in metacognition research* (pp. 63–80). New York: Springer.

Olson, E. A., & Luciana, M. (2008). The development of prefrontal cortex functions in adolescence: Theoretical models and a possible dissociation of dorsal versus ventral subregions. In C. A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (pp. 575–590). Cambridge, MA, US: MIT Press.

Osman, M. (2010). Controlling uncertainty: A review of human behavior in complex dynamic environments. *Psychological Bulletin*, *136*, 65–86.

Overbeek, T. J. M., Nieuwenhuis, S., & Ridderinkhof, K. R. (2005). Dissociable components of error processing: On the functional significance of the P_E vis-à-vis the ERN/N_E. *Journal of Psychophysiology*, *19*, 319–329.

Pailing, P. I., & Segalowitz, S. J. (2004). The effects of uncertainty in error monitoring on associated ERPs. *Brain and Cognition*, *56*, 215–233.

Pasquali, A., Timmermans, B., & Cleermans, A. (2010). Know thyself: Metacognitive networks and measures of consciousness. *Cognition*, *117*, 182–190.

Paz-Alonso, P. M., Ghetti, S., Matlen, B. J., Anderson, M. C., & Bunge, S. A. (2009). Memory suppression is an active process that improves over childhood. *Frontiers in Human Neuroscience*, *3*, 24–30.

Pillow, B. H., & Anderson, K. L. (2006). Children's awareness of their own certainty and understanding of deduction and guessing. *British Journal of Developmental Psychology*, *24*, 823–849.

Platt, M. L., & Huettel, S. A. (2008). Risky business: The neuroeconomics of decision making under uncertainty. *Nature Neuroscience*, *11*, 398–403.

Plude, D. J., Nelson, T. O., & Scholnick, E. K. (1998). Analytical research on developmental aspects of metamemory. *European Journal of Psychology of Education*, *13*, 29–42.

Povinelli, D. J., Landau, K. R., & Perilloux, H. K. (1996). Self-recognition in young children using delayed versus live feedback: Evidence of a developmental asynchrony. *Child Development*, *67*, 1540–1554.

Price, M. C., & Norman, E. (2008). Intuitive decisions on the fringes of consciousness: Are they conscious and does it matter? *Judgment and Decision Making*, *3*, 28–41.

Reber, R., Schwartz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality and Social Psychology Review*, *8*, 364–382.

Revelle, G. L., Wellman, H. M., & Karabenick, J. D. (1985). Comprehension monitoring in preschool children. *Child Development*, *56*, 654–663.

Ridderinkhof, K. R., Ullsperger, M., Crone, E. A., & Nieuwenhuis, S. (2004). The role of medial frontal cortex in cognitive control. *Science*, *306*, 443–447.

Ridderinkhoff, K. R., van den Wildenberg, W. P. M., Segalowitz, S., & Carter, C. S. (2004). Neurocognitive mechanisms of performance monitoring and inhibitory control. *Brain and Cognition*, *56*, 129–140.

Roberts, K. P., & Powell, M. B. (2005). Evidence of metacognitive awareness in young children who have experienced a repeated event. *Applied Cognitive Psychology*, *19*, 1019–1031.

Robinson, M. D., & Johnson, J. T. (1996). Recall memory, recognition memory, and the eyewitness confidence-accuracy correlation. *The Journal of Applied Psychology*, *81*, 587–594.

Robinson, M. D., Johnson, J. T., & Herndon, F. (1997). Reaction time and assessments of cognitive effort as predictors of eyewitness memory accuracy and confidence. *The Journal of Applied Psychology*, *82*, 416–425.

Rochat, P. (2004). Emerging co-awareness. In G. Bremner & A. Slater (Eds.), *Theories of infant development* (pp. 258–283). Malden: Blackwell Publishing.

Roebers, C. M. (2002). Confidence judgments in children's and adult's event recall and suggestibility. *Developmental Psychology*, *38*, 1052–1067.

Rothbart, M. K., Ziaie, H., & O'Boyle, C. G. (1992). Self-regulation and emotion in infancy. In N. Eisenberg & R. A. Fabes (Eds.), *Emotion and its regulation in early development* (pp. 7–23). San Francisco, CA: Jossey-Bass.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., et al. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*, 1029–1040.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America*, *102*, 14931–14936.

Ruffman, T., Garnham, W., Import, A., & Connolly, D. (2001). Does eye gaze indicate implicit knowledge of false belief? Charting transitions in knowledge. *Journal of Experimental Child Psychology*, *80*, 201–224.

Santesso, D., & Segalowitz, S. J. (2009). The error-related negativity is related to risk-taking and empathy in young men. *Psychophysiology*, *46*, 143–152.

Santesso, D., Segalowitz, S. J., & Schmidt, L. A. (2005). ERP correlates of error monitoring in 10 year olds are related to socialization. *Biological Psychology*, *70*, 79–87.

Santesso, D., Segalowitz, S. J., & Schmidt, L. A. (2006). Error-related electrocortical responses are enhanced in children with obsessive-compulsive behaviors. *Developmental Neuropsychology*, *29*, 431–445.

Schneider, W. (1998). Performance prediction in young children: Effects of skill, metacognition and wishful thinking. *Developmental Science*, *1*, 291–297.

Schneider, W., & Lockl, K. (2002). The development of metacognition and knowledge in children and adolescents. In T. Perfect & B. Schwartz (Eds.), *Applied metacognition* (pp. 224–247). Cambridge, UK: Cambridge University Press.

Schneider, W., & Lockl, K. (2008). Procedural metacognition in children: Evidence for developmental trends. In J. Dunlosky & R. A. Bjork (Eds.), *Handbook of metamemory and memory* (pp. 391–409). New York, NY: Psychology Press.

Schulz, L. E., & Bonawitz, E. B. (2007). Serious fun: Preschoolers engage in more exploratory play when evidence is confounded. *Developmental Psychology*, *43*, 1045–1050.

Schwartz, B. L. (2002). *Tip-of-the-tongue states: Phenomenology, mechanism, and lexical retrieval.* New Jersey: Lawrence Erlbaum.

Scott, R. B., & Dienes, Z. (2010). Prior familiarity with components enhances unconscious learning of relations. *Consciousness and Cognition*, *19*, 413–418.

Shimamura, A. P. (2000). Toward a cognitive neuroscience of metacognition. *Consciousness and Cognition*, *9*, 313–323.

Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and social competence from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology*, *26*, 978–986.

Siegel, L. S., & Ryan, E. B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development*, *60*, 973–980.

Stemmer, B., Segalowitz, S. J., Witzke, W., & Schönle, P. W. (2004). Error detection in patients with lesions to the medial prefrontal cortex: An ERP study. *Neuropsychologia*, *42*, 118–130.

Strommen, E. A. (1973). Verbal self-regulation in a children's game: Impulsive errors on "Simon Says" *Child Development*, *44*, 849–853.

Thompson, C., Barresi, J., & Moore, C. (1997). The development of future-oriented prudence and altruism in preschoolers. *Cognitive Development*, *12*, 199–212.

Thorell, L. B., Lindqvist, S., Nutley, S. B., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science*, *12*, 106–113.

Topolinski, S., & Reber, R. (2010). Gaining insight into the "Aha" experience. *Current Directions in Psychological Science*, *19*, 402–405.

Van Boxtel, G. J. M., Van der Molen, M. W., & Jennings, J. R. (2005). Differential involvement of the anterior cingulate cortex in performance monitoring during a stop-signal task. *Journal of Psychophysiology*, *19*, 1–10.

van Veen, V., & Carter, C. S. (2002). The timing of action monitoring processes in anterior cingulate cortex. *Journal of Cognitive Neuroscience*, *14*, 593–602.

Weary, G., & Jacobson, J. A. (1997). Causal uncertainty beliefs and diagnostic seeking. *Journal of Personality and Social Psychology*, *73*, 839–848.

Weintraub, S., Dikmen, S. S., Heaton, R. K., Tulsky, D. S., Zelazo, P. D., Bauer, P., et al. (2011). NIH Toolbox for the assessment of behavioral and neurological function: Cognition domain instruments (under review).

Wiersema, J. R., van der Meere, J. J., & Roeyers, H. (2007). Developmental changes in error monitoring: An event-related potential study. *Neuropsychologia*, *45*, 1649–1657.

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology*, *35*, 205–213.

Xu, F., & Garcia, V. (2008). Intuitive statistics by 8-month-old infants. *Proceedings of the National Academy of Sciences of the United States of America*, *105*, 5012–5015.

Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences*, *8*, 12–17.

Zelazo, P. D., Carlson, S. M., & Kesek, A. (2008). The development of executive function in childhood. In C. A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience*. 2nd ed., (pp. 553–574). Cambridge, MA: MIT Press.

Zelazo, P. D., & Cunningham, W. (2007). Executive function: Mechanisms underlying motion regulation. In J. Gross (Ed.), *Handbook of emotion regulation* (pp. 135–158). New York: Guilford.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development*, *11*, 37–63.

Zelazo, P. D., Gao, H. H., & Todd, R. (2007). The development of consciousness. In P. D. Zelazo, M. Moscovitch & E. Thompson (Eds.), *The Cambridge handbook of consciousness* (pp. 405–432). New York: Cambridge University Press.

Zelazo, P. D., Müller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*(3).